5-2003

Combat effectiveness of the joint helmet mounted cueing system

Taylor N. Thorson

To the Graduate Council:

I am submitting herewith a thesis written by Taylor N. Thorson entitled "Combat effectiveness of the joint helmet mounted cueing system." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

R. Kimberlin, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Dr. R. Kimberlin, Major Professor

We have read this thesis and recommend its acceptance:

Frank G. Collins

Dr. F. Collins

Peter Solies

Dr. P. Solies

Accepted for the Council:

Vice Provost and
Dean of Graduate Studies

COMBAT EFFECTIVENESS OF THE JOINT HELMET MOUNTED CUEING SYSTEM

A Thesis Presented for the Master of Science Degree,
The University of Tennessee, Knoxville.

Taylor N.Thorson
May 2003

Dedication

This thesis is dedicated to Bob Thorson who would have loved this.

Acknowledgements

I would like to expressly thank the Advanced Weapons Laboratory in China Lake, California for the opportunity to fly this system.

Abstract

The Joint Helmet Mounted Cueing System was designed to allow situational awareness in the arena of within visual range and beyond visual range air to air combat with the ancillary phase of air to ground weapons employment. This system was tested on the ground and during flight test comprising of approximately 37 flights by the author. It was found to be a significant improvement in capabilities of both the air to air and air to ground roles of the F/A-18 Hornet.

Preface

This thesis relies on an existing display system currently fielded in the F/A-18 E/F Super Hornet aircraft. For classification purposes, this thesis should be considered Unclassified. Any reference to a HOBS missile system will assume a missile that can exceed 45 degrees of off-boresight angle in 3-D space.

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Nomenclature

A/A	Air-to-Air
A/G	Air-to-Ground
BFFT	Buffet
BVR	Beyond Visual Range
CNPY	Canopy
CG	Center of Gravity
COM	Center of Mass
DAC	Dynamic Aiming Cross
DAG	Display Advisory Group
DDI	Digital Display Indicator
DU	Display Unit
EU	Electronics Unit
F/A	Fighter/Attack
FIX LOS	Fixed Line of Sight
FLIR	Forward Looking Infrared
FSU	Former Soviet Union
HACQ	Helmet Radar Acquisition
HMD	Helmet Mounted Display
HOBS	High Off Boresight System
HRC	Helmet Release Connector
HUD	Head's Up Display
HVI	Human Vehicle Interface
IR	Infrared
JHMCS	Joint Helmet Mounted Cueing System
L&S	Launch and Steering Target
MRU	Magnetic Receiver Unit
MTU	Magnetic Transmitter Unit
NAV	Navigation master mode
NM	Nautical Miles
NVG	Night Vision Goggle
ORD	Operational Requirements Document
QDC	Quick Disconnect
QMB	Quick Mounting Bracket
REJ	Reject
SCS	Software Configuration Set
TD	Target Designator
TDC	Throttle Designator Controller
WVR	Within Visual Range

Chapter 1

Background

In 1984, the Former Soviet Union (FSU) fielded the AA-11 Archer (NATO Designation) High Off Boresight System (HOBS) Infrared Missile coupled with a Helmet Mounted Sight into the MiG-29 Fulcrum and SU-27 Flanker fighter aircraft. The United States has been at a deficit in the within visual range (WVR) arena since.

Indeed, Global Defence Review, Ltd noted:

> Helmet-mounted sight-and-display technology has the potential to transform air combat fundamentally, allowing combat aircraft and helicopters pilots to look at a target and fire a guided weapon. One industry expert said: "helmet systems are now an essential element in the architecture of the weapon system". (http://www.ets-news.com/hud.htm)

The Israeli company Elbit and Kaiser fielded the first operational helmet mounted display for the Israeli Air Force called the DASH helmet in the mid 1990's. The United States capitalized on that design by generating an Operational Requirements Document to field a system to provide situational awareness to the pilot and to cue a HOBS missile (the winner of the AIM-9X competition). Boeing (then McDonell Douglas) won the contract and produced the first JHMCS system in concert with Kaiser Electronics, Visual Systems, Inc (VSI), and Elbit Corporation.

The proliferation of helmet mounted displays has been undertaken for a plethora of aircraft, including: F-35 (Joint Strike Fighter), Eurofighter, MiG 21, Rafale, to name a few.

A design advisory group (DAG) was held to implement F/A-18 symbology under the 15C Software Configuration Set (SCS) to be tested in the F/A-18 C/D family of aircraft. The JHMCS will be currently fielded only in the F/A-18 E/F family of aircraft, however. The author's first JHMCS test flight occurred in October 2000. The author's final JHMCS developmental test flight occurred in September 2002.

Chapter 2

Aircraft Description

The F/A-18 Hornet is a multi-mission single or two seat aircraft that can deliver a variety of combat stores against airborne and surface targets. It uses either the APG-65 or APG-73 radar to cue its sensors, and usually incorporates a Forward Looking Infrared Receiver (FLIR) for cueing, also. It has a laser ring gyro inertial navigation system for position keeping. It has two afterburning GE-400/410/414 turbofans, and is capable of supersonic speeds. It is currently fielded with a -3 to + 7.5 g limit. The aircraft uses "master modes" to determine store delivery and display settings. One is air-to-air (A/A) master mode for engaging airborne targets using missiles and a 20 mm cannon. A second is navigation (NAV) master mode for takeoff, landing, and instrument flying. Lastly, there is an air-to-ground (A/G) master mode for engaging surface targets with conventional and guided ordnance. The traditional F/A-18 uses a head's up display (HUD) and three digital display indicators (DDI's) for showing a variety of displays (e.g. radar display, stores display, HUD repeater, etc).

Chapter 3

System Description

Concept of Operations

The design selected for the F/A-18 utilized a magnetic system to allow determination of JHMCS position and orientation. A magnetic map of the cockpit is performed and loaded into the electronics unit (EU) for constant reference of JHMCS placement. This map is transmitted into the cockpit by a magnetic transmitter unit (MTU). A magnetic receiver unit (MRU) takes the transmitted map data and processes the position of the JHMCS within the map in x, y, z and orientation (roll angle). The processing that occurs within the EU accurately locates the JHMCS and displays the symbology to the pilot (see figure 1).

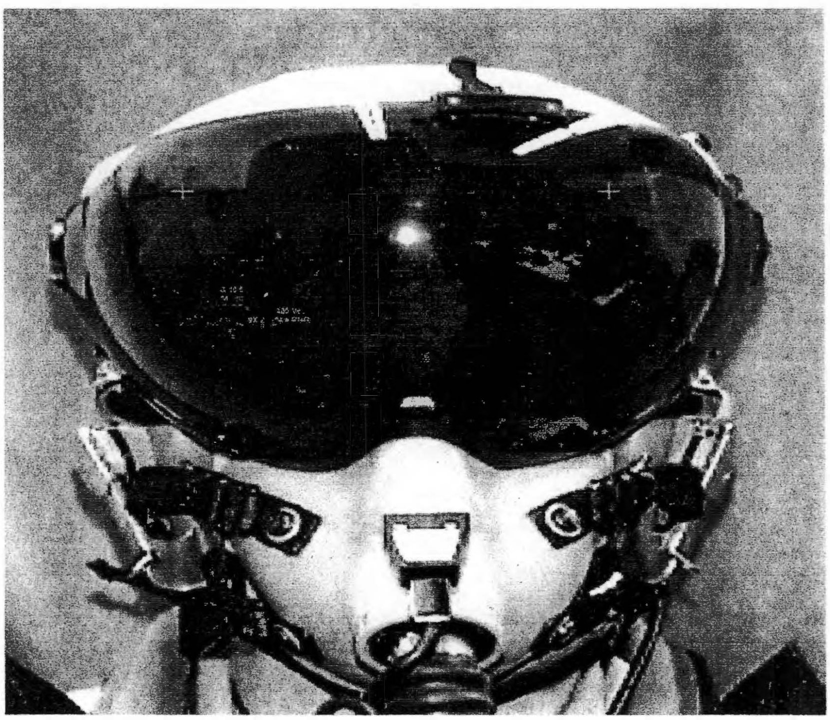

Figure 1 Introduction to the JHMCS

JHMCS Unique Hardware in the F/A-18

The modification to the F/A-18 to support JHMCS integration consisted of moving electrical components to allow for the placement of two additional units called the Electronics Unit (EU) and Controller Unit (CU) that process helmet mounted display (HMD) data to provide the image and position information to the system for an accurate depiction of aircraft/HMD state. Additionally, a magnetic transmitter unit (MTU) was added just aft of the ejection seat on the port side of the cockpit mounted to the canopy rail to constantly transmit the magnetic map into the cockpit (see figure 2).

A cord connects the JHMCS helmet shell to the high voltage power supply (8,000-10,000 volts) to deliver three-phase power to the JHMCS. The power supply knob is located on the right side of the glare shield and replaced the existing MAP GAIN knob, which was rarely used (see figure 3). It uses a knob that travels approximately 300 degrees of travel from off (soft detent) to full bright.

MTU→

Figure 2 MTU Location

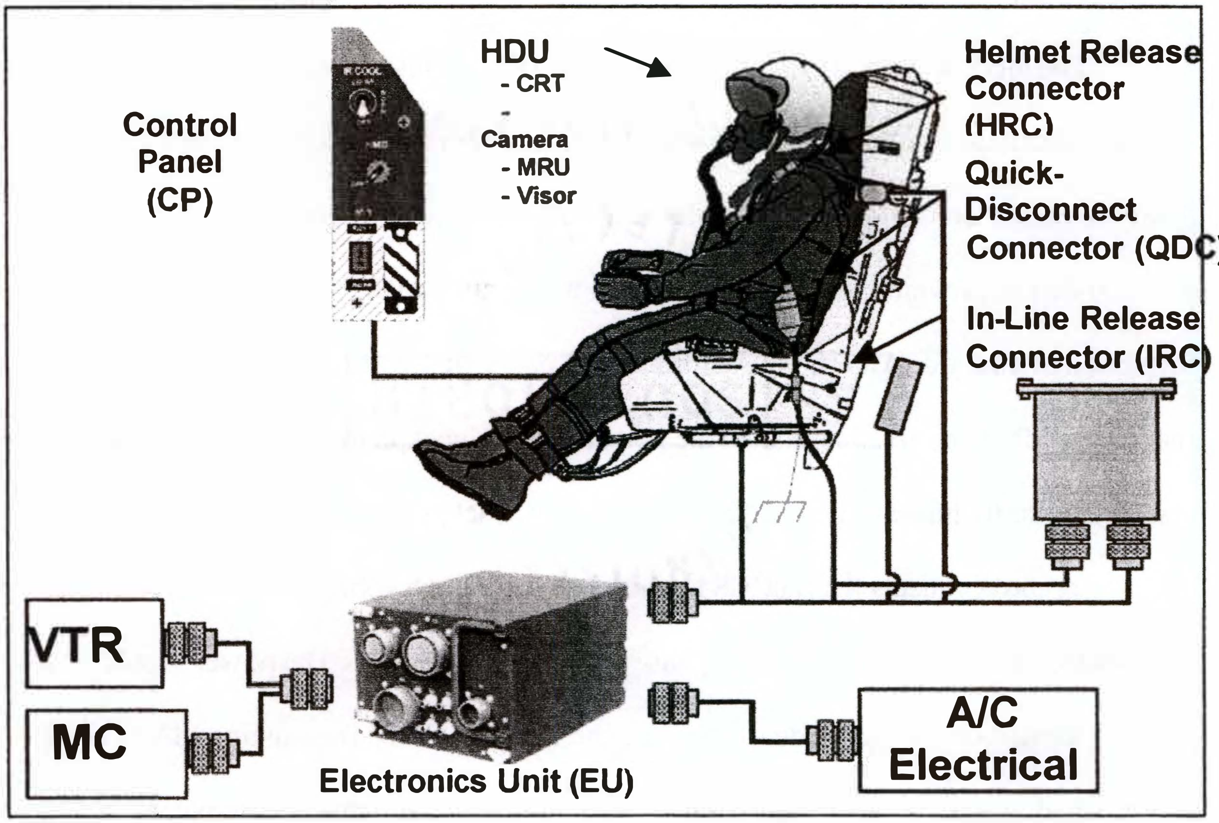

Figure 3 Overall Schematic

<u>Physical Characteristics</u>

The JHMCS helmet and upper human vehicle interface weighs 4.2 pounds, compared to a standard aviator's helmet at 3.1 pounds. However the center of gravity has moved forward approximately 2 inches (towards the front of the helmet). It is a standard HGU-55 (US Navy designation) that has been modified for JHMCS wiring. The HVI enters the rear of the helmet at a 15 degree angle (towards pilot's right shoulder) to preclude HVI twisting during normal head movement in flight.

An obvious issue for a forward CG placement about the head is:

> The design of the HMD is such that the display is positioned in front of the eye, and thus the majority of the head mounted weight is forward of the head. This shifts the COM of the head more distal of the head-neck fulcrum increasing the moment of the head COM about the fulcrum. This results in a greater neck muscle force being required to control head movement. Altered myogenic function may subsequently lead to changes in head posture and pathomechanics of the cervical spine. (Baber et al, http://www.bham.ac.uk/ManMechEng/IEG/monet.html)

However, to date, no physiological problems have been noted in aircrew.

The HGU-55 Aviator's helmet shell has been slightly modified to allow placement of the display unit (DU), power to the DU, and data to be transferred to and from the JHMCS. See figure 1.

Display Unit

The DU contains all the electronics to adequately present the image to the aircrew. Inside the DU (figure 4), there exists the CRT, uplook reticle display, the MRU, the mounting pins, and camera.

Upper Human Vehicle Interface (HVI)

The power/data supply cord is separated into several parts. The helmet release connector (HRC) is placed approximately half-way between the quick disconnect (QDC) and the HGU-55 shell. The HRC is present to allow the helmet to separate from the quick mounting bracket (where the QDC is latched onto the pilot's torso harness) in case the helmet is lost during ejection (which is known to happen somewhat frequently) and is rated for approximately 100 pounds of force to separate. The QDC connects the aircrew portion of the JHMCS to the aircraft segment of the JHMCS.

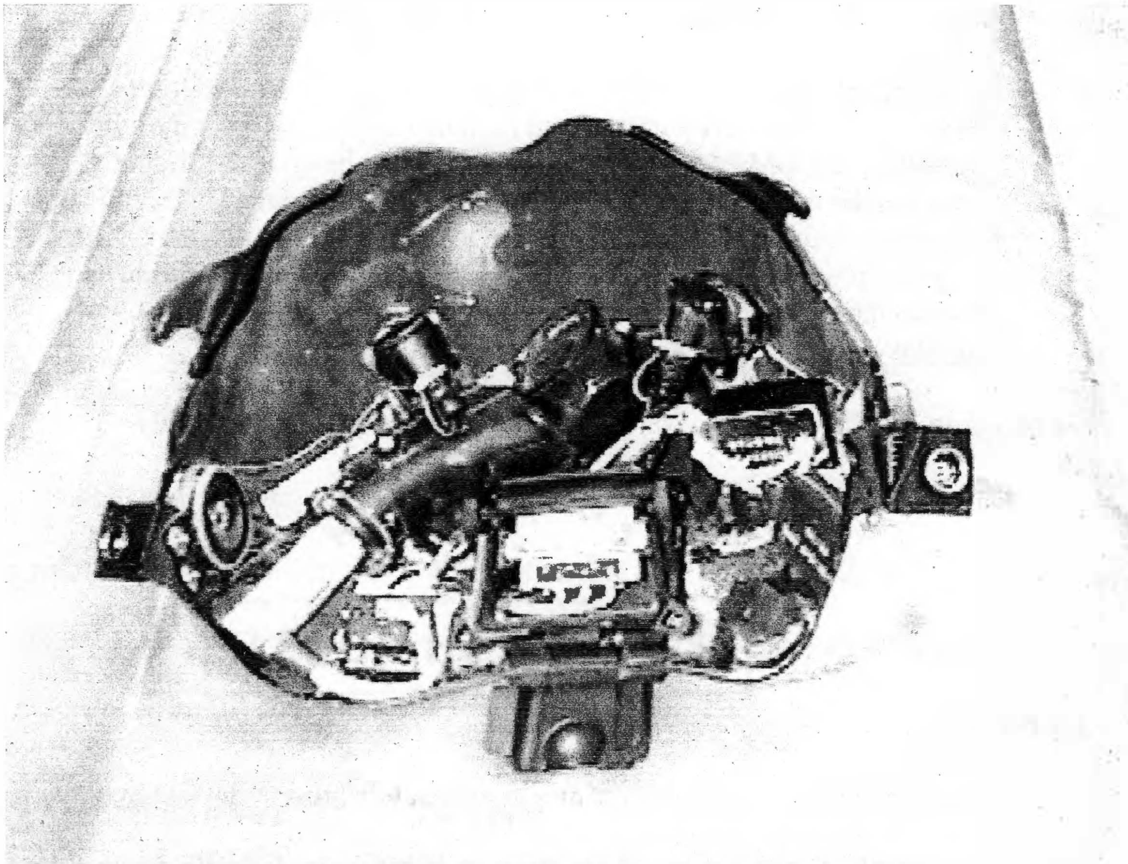

Figure 4 Display Unit (Shown upside down relative to helmet)

Lower HVI

The lower HVI rests in a bracket on the aft port side of the front cockpit when not attached to the pilot. It consists of the other half of the QDC and an in-line release connector (IRC). This is present in case the physical mechanization of rapid egress or ejection does not release the QDC and is a back-up (taking 60 pounds of force to separate).

Flight Equipment

The JHMCS is worn as a normal helmet when in the aircraft. The cord leaves the back of the HGU-55 shell and wraps around the back of the neck onto the left shoulder and down the front of the torso harness. A modified life preserver is used to accommodate the JHMCS. Just below the HRC, the cord is snapped onto the front of the harness. The QDC clips into a bracket near the left hip of the pilot, called the QMB. See figure 3.

Chapter 4

Displays

General

The JHMCS uses a monocular display placed over the right eye for cueing. Additionally, two uplook cursors are provided for additional cueing beyond normal neck movement limits. The fitting process places the display "over" the pilot's right eye (see figure 1) so as to ensure full vision (no obscuration) of the display.

Brightness

The JHMCS has three selections for brightness: day, night, and automatic. A dark visor is used during all daylight operations. A clear visor is used for night mode. Selecting night will limit the maximum brightness of the HMD. Automatic mode senses the existing light conditions via the camera inside the DU. This sets the maximum brightness as a function of perceived ambient lighting.

Air-to-Air (A/A)

Below is the JHMCS air-to-air display (figure 5). Calibrated airspeed is displayed in nautical miles per hour. Altitude is displayed in feet (MSL or AGL). True angle of attack in degrees, true Mach number, and aircraft n_z are also displayed. The + (enlarged plus symbol) symbol in the middle of the display is called the dynamic aiming cross (DAC). When helmet radar acquisition (HACQ) is commanded, the radar is slaved to the DAC (as indicated by the segmented circle immediately surrounding the DAC on the display below). Similarly, when a HOBS missile is selected, the seeker symbol is slaved to the DAC unless it is in track. The top number on the display is the elevation of the JHMCS as measured by the DAC relative to the earth's horizon. The compass rose seen

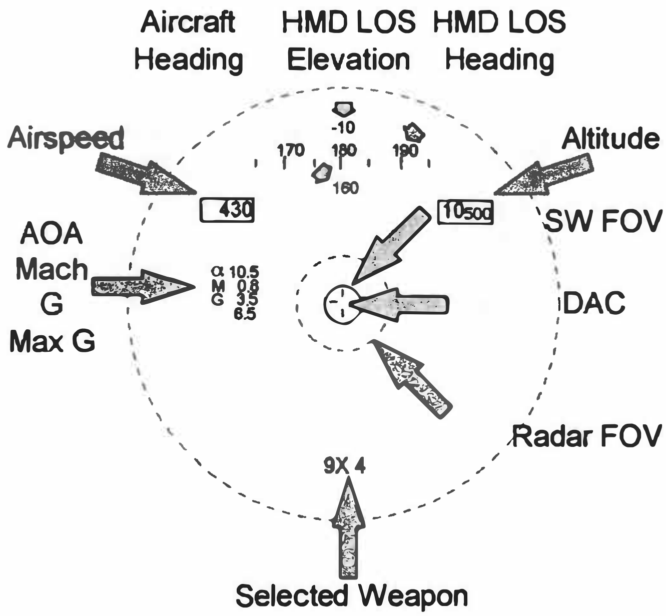

Figure 5 Air-to-Air Display (no radar target)

as the top of the HMD is HMD line of sight heading measured to the DAC. Aircraft heading (true or magnetic) is displayed immediately below the compass rose. Additionally, the selected weapon (Sidewinder, Sparrow, AMRAAM, or GUN) with the number of the selected stores actually loaded on the aircraft are displayed.

If a radar target is present (called the L&S (Launch and Steering target)), then the display immediately transitions to the below figure (figure 6). A target designation (TD) box appears to give cueing to the pilot of the placement of the designated target relative to the aircraft. A target source readout appears. For the purposes of this thesis, the L&S will always be provided by the radar. Closing velocity (Vc), range in nautical miles, and time of flight information are displayed as well. A normalized in range display (NIRD) circle gives information regarding maximum range, range of no escape, and minimum range (all indicated by carats around the circle). A target aspect vector appears to

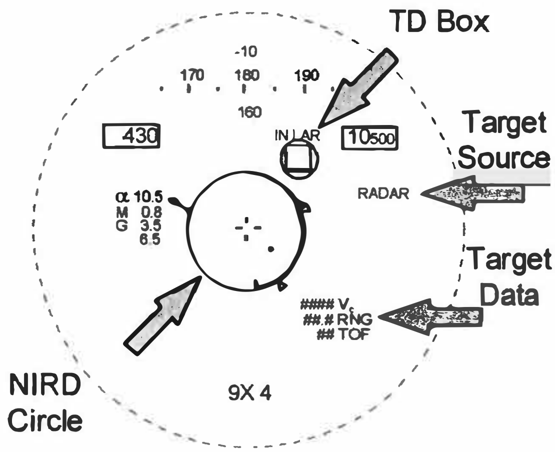

Figure 6 A/A Display with L&S

indicate the nose of the target relative to the F/A-18 as seen at the 9 o'clock position on the figure below. An aspect vector at 6 o'clock indicates the target is nose on to the F/A-18. When the Sidewinder is the selected weapon, it is sent along the radar line of sight to acquire the target with its seeker (indicated by the circle surrounding the TD box). The sidewinder can track without the presence of the radar and is indicated by just the circle being displayed. If the TD box is not present in the HMD, it flashes at the limits of the display nearest the actual target position and provides a target locator line (TLL) of varying length to indicate the position of the designated target (figure 7).

Uplook Reticles (see figures 1 and 8) are commanded whenever a HOBS missile is selected and the sensor select switch is placed aft (see figure 13). The main display ceases to function as a cueing source (all the information is still present, however) and the uplooks can then cue the HOBS missile to the target. The left uplook is commanded when looking left and the right uplook is commanded when looking right with a slight hysteresis region directly above the JHMCS.

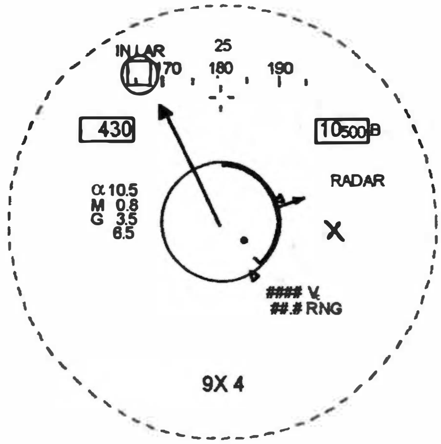

Figure 7 A/A Display with Target Locator Line

Air-to-Ground (A/G)

When A/G master mode is selected, the HMD immediately displays the A/G symbology as seen in figure 9. Note the absence of the DAC. The word HARM is written to disclose a text box that is out of scope for this report. AUTO is present to denote the type of conventional ordnance mode the aircraft is in. The B underneath the altitude box denoted barometric altitude ranging is active.

If an A/G target is designated, the display changes to figure 10. The diamond appears showing the target location if within the HMD FOV. The DAC appears and the steering is now automatically directed to the target (15.3 NM to the target).

If the HMD is moved such that the target is no longer within the FOV, a target locator line (TLL) appears to indicate offset to target (30 degrees in this case) and points to the target location (figure 11). Additionally, the target flashes when HMD limited.

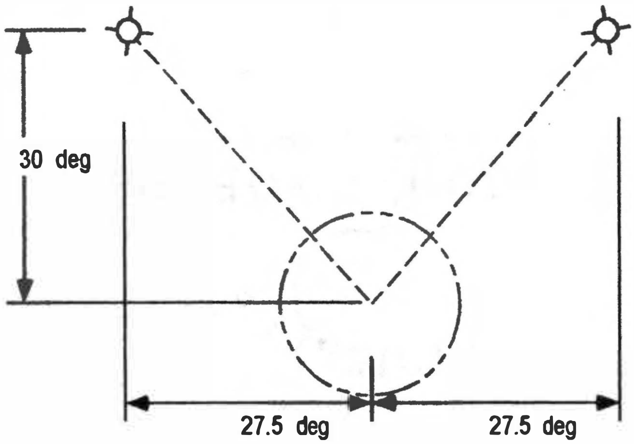

Figure 8 Uplook Reticles

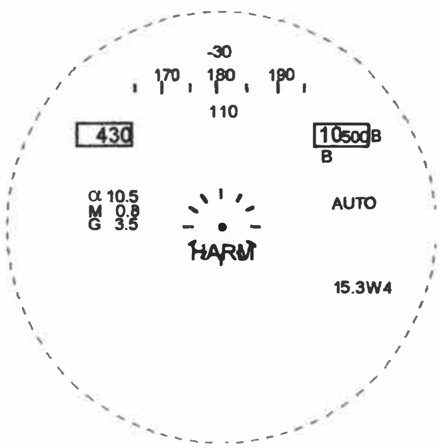

Figure 9 A/G Display with No Target Designated

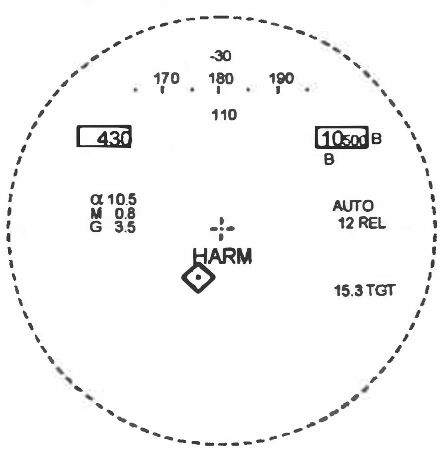

Figure 10 A/G Display with Target Designated

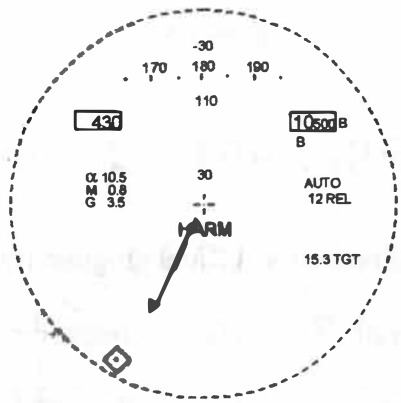

Figure 11 A/G Display with Target Locator Line Present

Chapter 5

Software Description

General

The aircraft SCS and EU operational flight program (OFP) determine JHMCS functionality internal to the aircraft. Any update/fix/improvement into the software can be accomplished at any time, however logistics and fleet configuration control demand any change proposed (unless it concerns safety of flight) must go through proper channels and usually take approximately 24 months to be implemented. This chapter concerns how the JHMCS operates within the aircraft SCS. EU software is out of scope of this thesis.

Top Level HMD Display

Below (figure 12) is the top level HMD display accessed through the HMD pushtile on the support menu of any DDI.

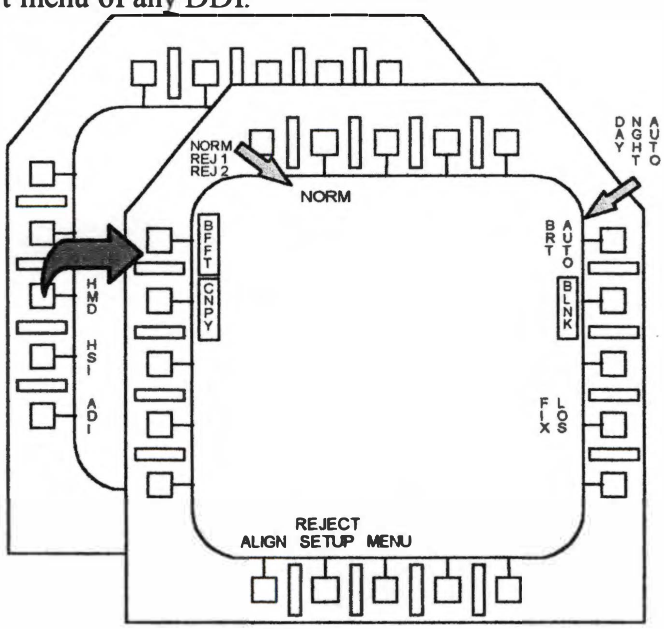

Figure 12 HMD Page on DDI and Associated Sublevel

Once selected, the top level display is brought up on the appropriate DDI. BFFT and CNPY are not used. FIX LOS is out of scope of this thesis. NORM is replaced by REJ 1 or REJ 2 (see declutter later in this chapter). Brightness can be selected as DAY, NIGHT, or automatic (AUTO). Blanking (BLNK) initializes selected and is discussed later in this chapter.

Built in Test (BIT)

A built in test parameter is monitored to report JHMCS status to the aircrew (see figure 13). These BITs consist of periodic BIT, start up BIT, and initiated BIT. Any degrade is reported to the aircrew on the BIT page on one of the DDI's. Any initiated BIT results in the display going through a test pattern and reports the result of the BIT as GO or degraded (DEGD).

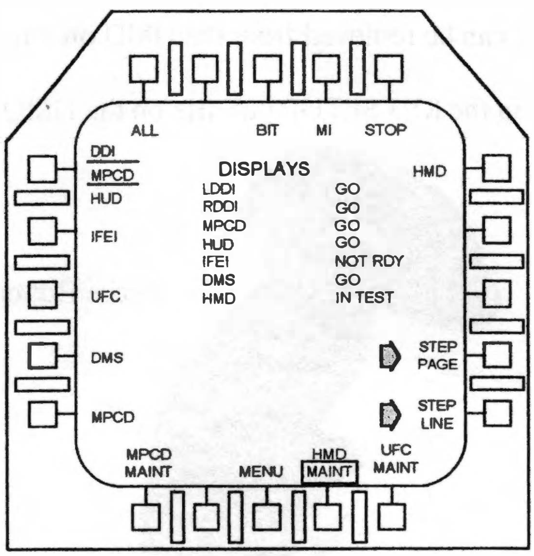

Figure 13 HMD BIT Page

Blanking

At the initial DAG, the JHMCS was designed to "blank," meaning to suppress the HMD when looking through the HUD or inside the aircraft cockpit below the canopy rail. It uses two areas of blanking: one for air-to-air master mode and one for both navigation and air-to-ground master modes. As the HMD is swept through these areas, all displays are blanked except for the dynamic aiming cross, Sidewinder seeker circle, and TD box. Automatic blanking can be de-selected from the HMD display. Additionally, the display can be blanked during normal operations immediately by depressing the recce button which is directly by the sensor control switch on the pilot's control stick (see figure 14).

Declutter Options

The JHMCS allows for all aspects of the information to be decluttered from the HMD (figure 15). There exist three declutter options: normal (NORM), declutter 1 and declutter 2. Any parameter can be removed from the HMD on any given declutter "level". This is accessed via the REJ SETUP pushtile on the HMD sublevel on the DDI.

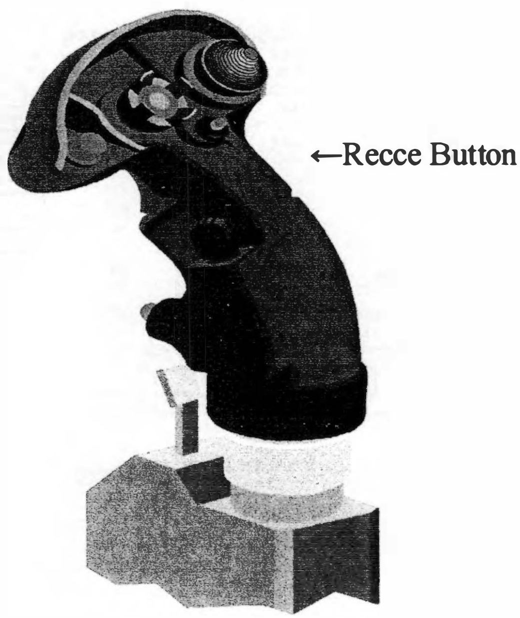

Figure 14 Control Stick

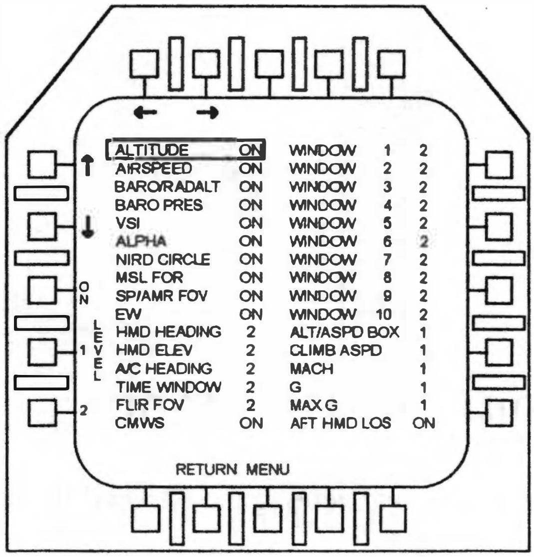

Figure 15 Declutter sublevel of HMD display

Alignment

Since the JHMCS position is based on a magnetic map, the position of the MRU is calibrated prior to each flight to ensure proper alignment of symbology. To align the JHMCS the canopy must be closed (the MTU is attached to the canopy). Align is selected from the HMD page and the HMD symbology is placed over the HUD symbology and a cage/uncage is selected from the throttle to initiate coarse alignment (figure 16). The alignment then automatically switches to fine align mode and further refinement of the symbology in x and y (indicated by dxdy on the HMD) and in roll (indicated by droll on the HMD) is accomplished by actuating the TDC and cage/uncage button on the throttle (figure 17).

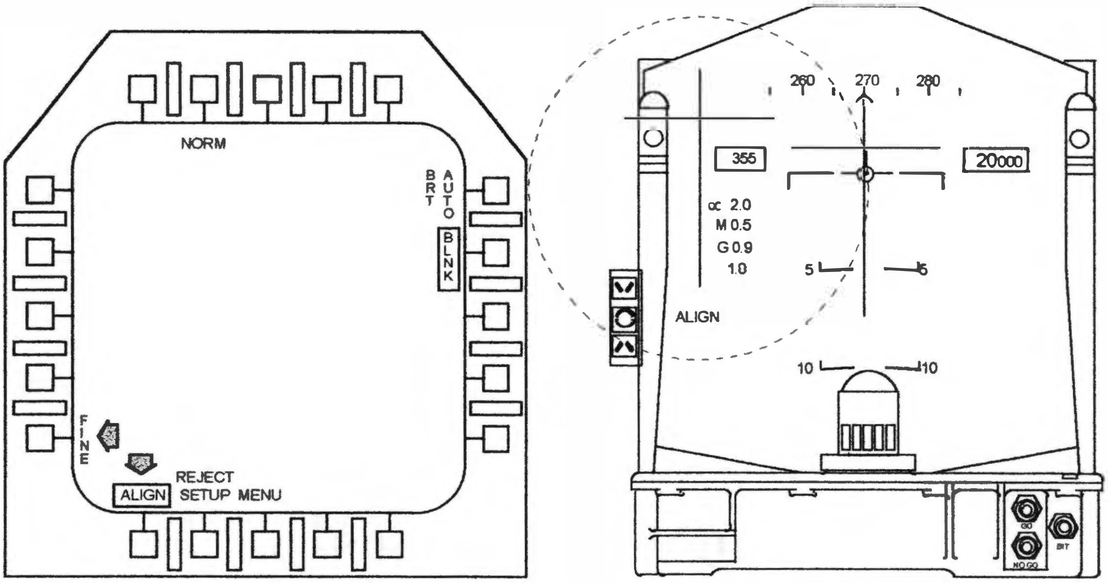

Figure 16 Alignment Sublevel and HUD/HMD Displays

Cage/Uncage Button →

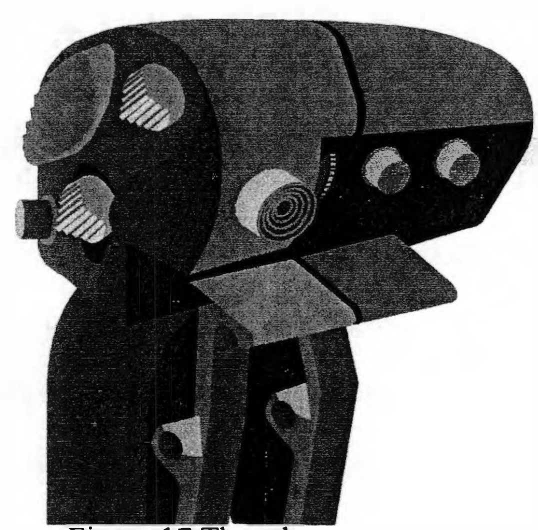

Figure 17 Throttle

Chapter 6

Human Factors

Fit

The initial fitting time was approximately six hours, including visor grind time (to fit oxygen mask, helmet visor receivers, and shape of face) and helmet fitting adjustment. After the initial fitting, a test bench was used to overlay the display onto the pilot's right eye. Several modifications and subsequent fittings had to be performed to ensure both a good helmet fit and display placement.

Comfort

Ground Operations

The JHMCS was found to be a snug, but comfortable fit. The upper HVI, once connected, was not cumbersome and did not restrict movement in any direction (left, right, up, down, or any combination thereof). Because of the tight fit, the sound attenuation (aircraft noise, voices) was a significant improvement over older helmets. However, the HGU-55 shell seemed to contract in cold weather and was uncomfortable and difficult to don and remained so until warmed by the aircrew's body temperature (approximately 10 minutes)

One g Flight

The JHMCS was also comfortable, and when compared to older helmets, tended to fit more snugly than legacy designs. During operational test, the JHMCS was worn for 6 hours consecutively while airborne with no deficiencies noted for comfort in flight.

High g Flight

The JHMCS was tested to 7.5 g under multi-plane engagements and during single ship operations. The forward CG of the JHMCS never caused the helmet shell to slip, however was noticeable in muscle stress induced into the neck by the additional weight/ CG loading. The forward CG was much less of a problem than when wearing night vision goggles, which significantly move the CG forward. Poor fit was noted during the first flight of several developmental test pilots. Any slip resulted in a loss of display because of the small size of the display and proximity to the eye.

<u>JHMCS Field of View/Field of Regard</u>

The JHMCS field of view is measured at 20 degrees. The field of regard is (measured by the author) to be 92 deg right and 86 deg left (measured without body twist). In the vertical, the field of regard is approximately 53 deg up and 38 deg down. Although advertised with an unlimited field of regard, the JHMCS can only be moved as much as the cockpit and human factors will allow. With body twist, the field of regard can be approximately 150 degrees left and right and around 80 degrees up. If the JHMCS is placed in a region of unknown/degraded mapping region, a MOTION BOX cue is given across the display to give feed back to the aircrew to return to a more favorable position in the cockpit. When the MOTION BOX cue is given, the display becomes very erratic causing JHMCS heading to spin and any cue-able sensor to be displayed very erratically throughout the display.

System Performance

Ground Operations

Donning the JHMCS takes approximately 1 minute, which includes placing the JHMCS on the head, snapping in the HRC, and mounting the QDC into the QMB. An additional 30 seconds is required to mate the lower HVI to the upper HVI once seated in the cockpit. From first power application (via the display knob on the right side of the glare shield) to power up takes approximately 1 minute 15 seconds. Aligning the JHMCS takes approximately 30 seconds.

Brightness/Focus

During daylight hours, aircrew flew with the HMD brightness at full bright in the day mode. In peak sunlight, the HMD was still dim, but useable. Testing of the AUTO function was not performed.

The focus of the display was very crisp and clear when looking outside the cockpit. When the eyes focused on something near (canopy rail, HUD bracket, inside the cockpit if BLNK was unboxed) then the image became very blurry. This was due to the focal length being set near infinity for the JHMCS and the eyes then focus at an image 3-4 feet away and the image cannot be properly seen along with the near object.

Takeoff and Landing

Because of the critical nature of takeoff and landings, the HMD was usually blanked (by the recce button on the control stick) during takeoff and landing to prevent possible fixation and to keep the pilot in his normal habit patterns when in close proximity to the ground. There is very little value added in having the display on during these phases. One annoyance noticed by aircrew was the presence of the DAC in the

HUD during landing. Once blanked, the DAC repeater in the HUD is still present and follows helmet cueing. During landing, this proved to be a distraction, and while this system was not tested by Weapons Test Squadron China Lake in the carrier environment, all the test pilots felt that this would be unwelcome during those times, which precipitated the recommendation to turn the power off to the display during landing to remove the DAC repeater.

Debrief

The use of the HMD camera was also evaluated during debrief. The full flight could be viewed from standard 8mm videotape. Because the camera is located on the left side of the display, a certain amount of parallax was present which can easily cause some confusion when looking at air-to-ground video (accuracy of designation). This parallax can be removed through a somewhat cumbersome process of trial and error with the test set prior to flight. This process shifts the injected video onto the camera to compensate for the parallax. Additionally, the video is black and white with either white or green video overlay, causing some debrief difficulties when compared to the standard color HUD 8mm tape.

<u>HMD Performance</u>

Head Movement

There was no apparent lag between helmet movement and the displayed helmet parameters (HMD heading, elevation). However, due to the inertial lag in the HOBS missile and radar, there was some delay in repositioning the HOBS seeker head and the radar dish, respectively. There was no overshoot and the apparent damping ratio for movement was approximately 0.8.

Some deficiencies were noted, however, whenever the JHMCS was rotated when referenced to the aircraft axis; small deviations were observed between commanded and apparent line of sight (as indicated by the overlap between the HMD DAC and the HUD DAC).

Airspeed

The airspeed "box" displayed in the HMD matched the HUD indicated airspeed exactly with no apparent lag. Its placement in the HMD mimicked the HUD and was found to be agreeable.

Altitude

The altitude "box" displayed in the HMD also mimicked the HUD placement, but several times was found to be in approximately ten (10) feet of error under static conditions. Additionally, during rapid climbs and descents, the HMD would indicate climbs/descents to the nearest 10 feet, while the sample rate on the HUD skipped several hundred feet while incrementing/decrementing. This was an annoyance for aircrew, but was not found to be objectionable.

Aircraft Heading

The digital heading indicator exactly matched aircraft heading with no apparent lag during all static and dynamic points. Its placement caused confusion among early flights due to aircrew misinterpreting the heading as JHMCS heading. After several familiarization periods, aircrew became used to this and were able to effectively process the displayed information.

JHMCS Heading

The "compass rose" was correctly interpreted as the JHMCS was moved around the cockpit. The quick rate at which the compass rose could "spin" was not found to be objectionable because during periods of rapid head movement, aircrew were focusing on the DAC and not the JHMCS heading.

JHMCS Elevation

The elevation of the DAC was also evaluated in both static and dynamic testing. During straight and level flight, the elevation was accurate within one degree. However, when in an angle of bank, the errors were not consistent and exceeded five (5) degrees in many scenarios. This caused much confusion of aircrew who were trying to relay information along a line of sight to a target when in an angle of bank.

Other Aircraft Information

The angle of attack, Mach, aircraft g, and peak g were also evaluated and were satisfactory in all regimes of flight. The angle of attack and aircraft g were some the most frequently referenced numbers during dynamic (basic fighter maneuvering) tests.

RADAR Information

The NIRD and ASE circles also were found to mimic HUD placement in the HMD. This allowed a seamless transition between HUD information and HMD information. However, the target aspect vector was not the same size/format on the HMD as in the HUD. This led to confusion to determine correct target aspect from the HMD until several flights were conducted for familiarization. Additionally, the steering "dot" (present for missile cueing) that appears with every target was much too small to be correctly discerned without scanning much of the HMD to determine "dot" status.

DAC Placement

Dynamic aiming cross placement was also evaluated. With the exception of one area, it was placed with ease throughout all head locations. This exception occurs in the +5 to +10 area of DAC elevation. To accommodate for head movement limitations in the vertical (up direction), the DAC is "accelerated" through this region to allow greater look angles (measured relative to the DAC) while looking up. Placement of the DAC on a target in this area proved difficult because of the additional movement of the DAC. This, too, required several familiarization periods with the HMD.

Blanking Regions

The two blanking regions were also evaluated during the test phase. The A/A region was found to be acceptable with advertent HMD blanking occurring near the HUD. As the HMD was near the HUD, the HMD would blank, however the information for placing the sensor (RADAR or HOBS missile) was still available on the HUD. This transition proved difficult for all aircrew, but was still managed by shifting focus to the HUD or moving the HMD away from the HUD to restore the display.

The A/G region was found to be too large in the A/G mode. This was most apparent when designating ground targets near the HUD with the TDC. As the HMD was blanked, the ability to place an A/G sensor (FLIR or RADAR) was precluded. Aircraft movement of 5-10 degrees of heading was required to "unblank" the HMD.

Chapter 7

A/A WVR Warfighting Performance

System Performance

For all JHMCS pilots polled in developmental test, it took an average of 10 flights (approximately 15 hours) before all of the information presented could be assimilated and used. The typical pilot continued to reference the HUD for flight information until he was comfortable referencing the HMD. Until that point, the HMD was merely used as a system used to direct a sensor (HOBS missile or radar) for weapons employment. As time increased with HMD use, the full capability of the HMD was exploited. Still, however, the HUD must be referenced for pitch and roll (attitude) information.

Situational Awareness

Initially, aircrew continued to reference the HUD for airspeed and altitude information until approximately 15 hours of flight time with the HMD. Aircrew would slowly assimilate the information presented. The realization that the HMD is a static source (placed in front of right eye when looking straight ahead) was difficult for some to grasp. Aircrew rely on moving their eyes to keep track of the target when maneuvering and would frequently have to make a conscious decision to move their right eye to the display to gain information. The information on the HMD was found to exactly match the HUD with no apparent lag, despite high rates of turn and heavy g loading.

Targeting/Employment

On the first flight, targeting using the radar or HOBS missile was extremely easy. Under g, the targeting became somewhat more difficult to place the DAC on the target because of increased "weight" of the helmet under g and because some regions of heavy buffet can be encountered during basic fighter maneuvering as well. Fifty to sixty degrees of helmet travel was the average limit when under high (6-7) g loading. The use of uplooks allowed the aircrew to continue directing the HOBS missile if helmet travel was inhibited by neurotransmitters (pain/discomfort). All aircrew found the uplooks initially difficult to command and de-select. Typical problems encountered were not having a HOBS missile selected, forgetting that vertical acquisition (an ACM radar mode that is commanded similarly to uplook selection when non-JHMCS equipped) is removed with JHMCS, and being unable to de-select uplooks to return to the main display. Once the switchology was reviewed and aircrew were comfortable with the procedures, comfort level increase allowed useful application of the uplook potential. One problem noted during testing was the washout of the target beneath the bright uplook reticle during dim lighting conditions or when the target was small as compared to the uplook (i.e. when the target distance from the aircraft was greater than approximately 3 NM). However, the existing interface of weapons (e.g. 1500 Hz tone for AIM-9 track) gave the aircrew rapid feedback in case the HMD was not being referenced at the time (uplooks).

As both aircraft came into the merge, again, it took at least 15 hours of JHMCS "flight time" to bring airspeed and aircraft g into one's scan when entering the fight. Mainly, the JHMCS is used strictly for targeting either a HOBS missile or the RADAR into the bandit when the opposing aircraft is within the field of regard of either sensor. After around 15 hours has elapsed, the pilot began to bring airspeed, altitude, AOA, and aircraft 'g' into his scan and began to use the JHMCS as more than just a sensor/targeting tool.

Typical scenario

Turning fight

As both aircraft enter the merge at 15,000 feet MSL and 400 KCAS respectively, both aircraft turn across each other's tails and begin to enter the air combat maneuvering arena. Upon passing the bandit, if the pilot has a HOBS missile, he selects that missile and waits for the target aircraft to enter into the FOR of the missile. As he is waiting, he can continue to monitor his aircraft's energy state (altitude, airspeed, bleed rate, AOA and 'g') to optimally fly his aircraft. The solid line that appears in the HMD denoting maximum field of regard for the missile aids the pilot to know when to begin to concentrate on targeting the missile onto the opposing aircraft. With a good lock, a simulated missile shot is taken and the engagement is rapidly over with the JHMCS pilot getting first shot and kill over approximately 80% of the time (measured during flight test) compared to a non-JHMCS equipped aircraft.

With no HOBS missile, the aircrew must rely on getting within the RADAR FOR for the first shot. The JHMCS pilot can quickly realize first shot and kill over approximately 60% of the time (measured during flight test), depending on geometry at the setup and provided missile performance parameters are not exceeded (minimum range or gimbal limit).

Chapter 8

A/A BVR Warfighting Performance

Situational Awareness

Maintaining SA during a BVR engagement using the JHMCS was easier than when engaged in a maneuvering fight. The information on the HMD did not preclude normal tasks during the run, such as keeping sight of the wingman and ensuring proper geometry. The addition of aircraft energy (airspeed) and altitude to normal scan was welcome, and enhanced the pilot's ability to maintain aircraft parameters. Once radar information (e.g. TD box, NIRD circle) was displayed, normal cockpit tasks were unaffected and the information displayed helped prosecute the intercept.

Initially, test pilots were rarely able to interpret all of the information on the JHMCS until approximately 15 hours of flight time in this environment were completed. Invariably, test pilots would slowly be able to incorporate additional information from the HMD. The information would usually start with TD box placement, then altitude and airspeed infonnation (along with aircraft heading). Later, the NIRD/ASE circle would begin to be used on the HMD for information. Lastly, navigation information, AOA, Mach, and g would begin to be referenced during flight.

Targeting

The HMD provided ample cueing of target position and aspect. With more than one target displayed (creation of a DT2), better intercepts were conducted. Weapons information was readily available and no problems were noted during WVR flight.

Use of TD Box

The visor used for the JHMCS is not significantly different (i.e. transmissivity) than normal visors used in legacy helmets. Tally ranges were not significantly different than when compared to the HUD. However, the JHMCS allowed off boresight tallies at greater ranges than without a cueing source. Typically, off boresight tallies when using the HMD were approximately 4 NM better than when compared to standard off boresight tally ranges.

Typical Scenario

At the beginning of the intercept, the JHMCS was used for ownship awareness of altitude, airspeed, and some rudimentary navigation functions. As the intercept proceeded and an L & S could be generated from the radar page, SA to the target could then be gleaned from the JHMCS. Use in this scenario was primarily scanning target range and bearing from the JHMCS (as provided by the radar), as well as target aspect and Vc. Any change in these parameters was interpreted, but would usually cause the pilot to reference another display for precise information, which is similar tooperations that are HUD only.

As the fighter approaches visual range (nominally 5 NM) to the target, tallies could be gathered on all bandits, even when outside the HUD FOV. This always allowed greater SA in the within visual range combat arena.

Chapter 9

A/G Warfighting Performance

Overall Display Evaluation

Because the HMD is essentially the same in the air to ground arena, the information presented to the aircrew afforded a nearly seamless transition from the air to air into the air to ground arena. One notable exception was the absence of a DAC if a target was not designated. This initially caused much confusion for aircrew if they had not flown the system in the A/G arena, and was always an item discussed during post-flight.

Target Designation

Target designation consisted of assigning the TDC forward into the display and then simply looking onto the ground and depressing the TDC. An A/G "diamond" was then created in both the HMD and the HUD which cued all A/G sensors (e.g. FLIR) to the target. The target could then be slewed for further refinement. A quick reference to the FLIR could help ascertain/refine target position.

One deficiency noted earlier was the blanking region near the HUD for A/G master mode. This initially caused many problems during target designation at or near the HUD. Compensating for this required aircraft movement or the deselection of the blanking option on the HMD display on the DDI. Unboxing BLNK was very disorienting for the aircrew when looking down or through the HUD because of overlap.

Target Locator Line

The target locator line was evaluated for ease of use and accuracy. When the diamond is not within the HMD FOV, an arrow is present to provide SA to the target.

The degrees off HMD boresight of the target is also present. This number was found to be accurate, but the arrow provided greater SA to the target by following the arrow with the HMD to gain/regain sight of the target.

Chapter 10

Night Performance

Description

The JHMCS uses the existing configuration during night testing and evaluation, with the exception that a clear visor is worn. Extensive ground testing was performed prior to the first night flight. The most significant deficiency in the JHMCS during night operations was the presence of a "ghosted" image within the HMD. Because of the reflective coating on the visor was designed to reflect the majority of the display, yet still remain transmissive for sight through the display, some of the display "leaked" through the coating and reflected off the outer surface of the visor displaced approximately 1/8th of an inch down and to the right of the intended display. This "ghosted" image was much dimmer than the intended image and could be mitigated by reducing the brightness of the display to the smallest setting. During the darkest of nights, however, the display could not be dimmed adequately to reduce the image. Indeed, the dimmest setting still had ghosting and was found to be too bright, reducing overall visual acuity at night.

Performance

The performance of the JHMCS during night operations was exactly the same as during the day (with the obvious exception of the ghosting). The helmet shell was also evaluated for donning and doffing the HDU to place NVG's on the helmet shell using the NVG bracket. Most aircrew in flight had great difficulty in donning the DU because of the exact placement required to place all of the connecting pins from the DU into the Universal Connector. In fact, donning/doffing the DU at night had to be rehearsed on deck for at least 10 minutes before it could be accomplished in the cockpit. One test pilot removed his helmet during flight to don the HDU.

Night Vision Goggle (NVG) performance was exactly the same as with legacy helmets. One additional factor was the QDC was still superfluously connected. There is obviously no need for this connection to remain when using NVG's because the NVG's are powered by individual batteries in the NVG bracket.

On one particular flight, the aircrew became completely disoriented with the HMD and ended up in a 25 degree dive and 40 degree angle of bank when looking off boresight and intending a 10 degree dive with zero degrees angle of bank. A recovery was rapidly initiated and further interviews with JHMCS test pilots revealed similar incidents when in night or instrument meteorological conditions (IMC). This further reinforced that the JHMCS is not a flight path indicator and can result in very insidious aircraft conditions if extreme care is not used and visual meteorological conditions cannot be maintained. Subsequently, all flights included briefing instructions when encountering inadvertent IMC to blank the display.

Chapter 11

Conclusions

Clearly, The full utility of the Joint Helmet Mounted Cueing System has yet to be explored throughout every mission that the F/A-18 can fly. However, it's potential to revolutionize air-to-air combat for United States Naval Aviation cannot be overstated. Throughout flight test, the JHMCS was primarily involved in the within visual arena air combat. From the ability to quickly don the JHMCS, apply power and be fully combat effective in under three minutes lends itself to combat credence. Indeed, because of the limited deficiencies in the performance of the system, its utility in the air to air arena to quickly acquire targets will garner US aircrew an incredible advantage in weapons employment. Also, use of the information provided within the display greatly helped the aviator keep awareness to almost the full complement of aircraft flight parameters will enhance survivability and lethality. The use in BVR combat and air to ground roles will also greatly enhanced the warfighter's situational awareness and will allow the aircrew to spend a greater amount of time looking outside for threats and targets. Despite the drawbacks of increased weight, slightly forward CG of the JHMCS, and display flaws, it is an incredible capability and will directly result in a more capable warfighting system.

Chapter 12

Possible Improvements

Weight

While the JHMCS weighs only one more pound than normal flight helmets, its forward cg made the helmet shell slightly more cumbersome than normal flight gear. The use of lighter materials and a less cumbersome display unit would rectify this deficiency. Also, plumbing the HGU-55 shell for JHMCS operations would reduce the forward CG shift.

Velocity vector

Aircraft pitch attitude information is necessary during critical regions of flight when maintaining altitude is critical. Deciphering rate of change information to determine pitch attitude when turning is the only indicator of altitude loss. The vertical speed indicator (VSI) is not present in A/A or A/G master modes. A small velocity vector displayed in a corner of the HMD would greatly assist aircraft altitude keeping, particularly in the regions of low level flight and when trying to maintain aircraft altitude and attitude while scanning outside the cockpit.

Air to Ground Weapon Information

Similar to the velocity vector discussion, several parameters including steering for accurate ordnance placement, sensor usage, and ordnance selected could be added to the display, keeping in mind that the display can be "decluttered" at any time with a small pushtile actuation on the HMD page on the DDI.

Night/NVG incorporation

The JHMCS system should incorporate injected video onto the NVG tubes to assist in night situational awareness. Aircrew will continue to prefer to wear NVG's over JHMCS at night, because of the illuminative properties of the goggles, as compared to information on the HMD.

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Vita

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